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A simple means of improving the quality of speech from a diving helmet

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Summary

A simple device is described which combines a microphone amplifier with a noise gate to reduce the very high level of noise generated by a diving helmet air-demand valve. The device needs no adjustment, and can be accommodated within the helmet; it prevents the interspersion of speech by the extremely loud hissing noise which otherwise occurs every time the diver inhales.

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1. INTRODUCTION

Two methods are commonly used to supply a diver with air. The simpler and older is to pump air continuously from the surface via a hose; excess air escapes from under the diver's helmet or bell. This is known as the free-flow system. The alternative is the SCUBA (Self-Contained Underwater Breathing Apparatus) system which consists of one or more air bottles carried by the diver, and a 'demand valve' which supplies air only when the diver inhales; this is needed to conserve the finite quantity of air available to the diver.

SCUBA diving has the advantage of self-sufficiency, and is the usual choice of system for BBC broadcasts. Unfortunately, the demand valve generates a considerable amount of acoustic noise, whose level greatly exceeds the typical level of the diver's speech; in addition, the air noise is of a subjectively obtrusive nature which is detrimental to viewers' enjoyment of the programme, and fatiguing to programme staff.

Some years ago, at the request of the BBC Natural History Unit at Bristol, an air-noise suppressor circuit was developed[1]. This operates on the signal from the diver's microphone, using a tunable filter to identify the demand valve noise, which chiefly occupies the upper octave of the audio band. It needs continuous adjustment of the filter frequency, because the characteristics of the noise in the helmet depend both on ambient pressure (proportional to depth) and on the remaining pressure in the air bottle. The unit has been used very successfully in a number of programmes during the past ten years, but suffers from one major problem: namely, the difficulty of discriminating between speech and high-frequency noise. As might be expected, sibilants are the most difficult speech sounds to distinguish from unwanted 'hissing' noises. In addition, the recent adoption of a 'bubble' helmet, which provides an unobstructed view of the diver's face, rather than the previous type of helmet and mask (which resembles a wartime gas mask) has brought the unforeseen consequence that the noise spectrum more than ever resembles that of speech.

A recent decision to purchase rather than hire diving helmets has made it possible to obtain direct access to the air inlet system. This offers the advantage of much more positive discrimination between speech and air inlet noise, and forms the basis of a very simple noise suppressor which is compact enough to be fitted inside the helmet, thus ensuring that unpleasantly high noise levels never appear in any signal path. This offers practical and economic advantages over the alternative strategy of more sophisticated signal post-processing, and forms the basis of the equipment described in this Report.

2. CHARACTERISTICS OF DEMAND VALVE

In the SCUBA system, the air must be bottled at high pressure so that a reasonable amount can be carried in a bottle of manageable size. The bottles are filled to 205 bars, and the pressure at any later time is of course a direct indication of the amount of air remaining. To ensure the consistent operation of the demand valve, it is fed from the air bottle via a 'first stage' regulator at an approximately constant pressure of 8 bars.

The demand valve is a passive mechanical device which ensures that the pressure inside the helmet does not differ from that outside by more than about 0.005 bars. It therefore admits air to the helmet on detection of the very small relative pressure drop caused by the diver's inhalation. The valve is operated by a pressure-balanced piston, driven via a system of levers by a diaphragm of about 50 mm diameter, one side of which is exposed to helmet pressure, the other to external pressure. At peak flow rates of at least 10 litres/second. (corresponding to a typical full inhalation in 0.5 s, the maximum air velocity in the valve is very high, so that turbulent flow would be expected to generate very high sound pressure levels in the air inlet ducting.

From the demand valve, the air is admitted to the bubble helmet via two tubes of length about 150 mm and of cross-sectional area about 3 mm^2: see Fig. 1. The tubes are intended to direct the air stream against the front surface of the 'bubble' to prevent condensation; they have in addition three significant effects from the viewpoint of the work presently described. Firstly, by providing an acoustic mismatch, they greatly attenuate the noise in the helmet that would otherwise be generated by the demand valve. Secondly, the acoustic mismatch causes equally effective attenuation in the reverse direction, so that the diver's speech is similarly attenuated on its route to the demand valve. Thirdly, because of the viscosity of air, they cause a 'static' pressure drop of up to

about 1 bar, so that the pressure at the output of the demand valve can temporarily exceed the helmet pressure by that amount.

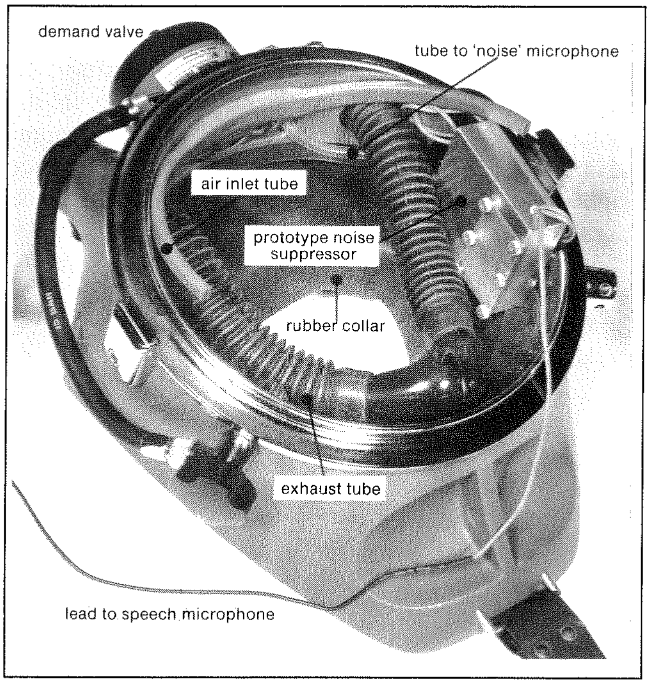

Fig. 1 - Photograph of diving helmet with 'bubble' removed, showing the features discussed.

By using a microphone connected pneumatically by a sealed tube to the demand-valve outlet, it is possible to achieve a high degree of discrimination between valve noise and speech. The noise pressure generated by the valve close to its output varies monotonically with flow rate, as shown in Fig. 2, which also indicates the static pressure drop in the tubing. As expected, the sound pressure levels are very high indeed, varying from 120 dB SPL on light

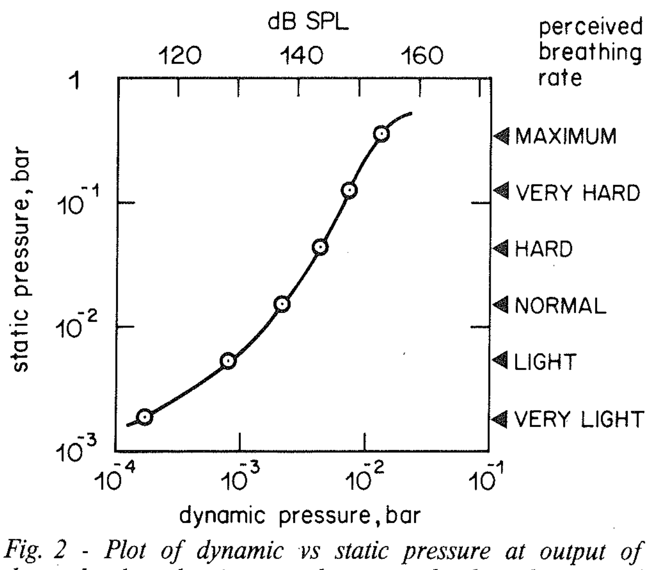

Fig. 2 - Plot of dynamic vs static pressure at output of demand valve, showing sound pressure levels and perceived inhalation rates.

breathing to more than 150 dB on full demand; such levels exceed those of the diver's speech by at worst about 30 dB, and are therefore very easy to identify by the use of simple circuitry.

As an aside, it is interesting to note how evenly spaced on a logarithmic scale are the authors' subjective perceptions of breath intake — *very light, light, normal, hard, very hard, maximum.* These comments were added only to provide some intuitive idea of air flow rate. The rate described as '*light*', corresponding to a sound pressure level of 130 dB SPL as perceived by the noise microphone, was chosen as the trigger level for the noise gate.

3. NOISE-SENSING MICROPHONE AND ITS ENCAPSULATION

The noise-sensing microphone should preferably be of small size, and must be capable of operating at extremely high sound levels; it must also withstand sudden pressure changes of up to 1 bar without damage and without momentary loss of output.

To determine the conditions of noise and static pressure as shown in Fig. 2, a semiconductor pressure sensor was connected by a tube to the outlet side of the demand valve. The sensor chosen has a bandwidth extending from DC to about 5 kHz; its dynamic range extends to 2 bars gauge pressure, far in excess of that for any known microphone. The use of a Fast Fourier Transform analyser for the measurements allowed the convenient display of pressure as a function of both time and frequency. The helmet is normally sealed around the diver's neck by a very close-fitting rubber collar, which is uncomfortable to wear in room conditions, and very difficult to fit and remove. The measurements were carried out by inverting the helmet, and breathing into it through a large funnel which was first inserted into the collar from inside the helmet, then pulled from outside by its spout until the collar gripped tightly around its cone profile, forming a good seal. The demand valve then of course 'thought' that the helmet was occupied.

Fig. 3 shows a typical plot of pressure against time for a breath intaken as sharply as possible. In Fig. 4 the noise spectrum is shown in third-octaves for the brief period of peak flow. The noise levels plotted in Fig. 2 represent the highest recorded amplitude in any third-octave band; this is typically at a centre frequency of 1.6 kHz.

Even though the noise-sensing microphone was to be sealed from water ingress, it was felt that if possible, a low-impedance (probably dynamic) type would be preferable to, say, an electret type which

depended on very high internal impedances; also, as the two other transducers in current use (earpiece and speech microphone) are passive, a passive noise sensor would enable all electronics to be placed outside the helmet if required, using a three-pair underwater connector. (Because of electrolytic effects, underwater connectors carrying DC can cause noise in nearby connectors carrying small signals, and electret microphones typically incorporate their own unity-gain preamplifiers which require a DC supply but still provide only very low signal levels.)

The first transducer to be tested as a noise detector was an earpiece identical to that already being used for surface-to-depth communication; a reduction in the number of *different* components in any system is of course always welcome. This device is of the moving-iron type; unfortunately, the iron diaphragm was forced against the magnet assembly by the static pressure, so that the dynamic output tended suddenly to disappear at high static pressures.

A brief investigation suggested that a sub-miniature moving-iron pressure microphone manufactured by Knowles Inc. might be suitable; with a response falling at about 12 dB per octave below 1 kHz, it seemed unlikely that it would be affected by the sudden rise in 'static' pressure shown in Fig. 3; the only matter for concern was its possible behaviour in the presence of extremely high sound pressure levels within its nominal frequency range of 1 to 5 kHz. In fact, the lower frequency limit is set by a hole punched in the diaphragm; no problems therefore occur due to ambient pressure changes, however large, provided that some limiting rate of pressure change is observed; although unknown, this rate apparently exceeds that of Fig. 3, which was readily tolerated by all of the individual transducers tested.

No problem was expected due to the sharp rise in pressure. Less predictably, the response of the microphone at high noise levels proved excellent; it remains linear up to about 140 dB SPL, and suffers a drop in sensitivity of only 6 dB at the maximum SPL of 154 dB. As previously mentioned, the chosen switching level for the noise gate is 'light' inhalation (130 dB SPL), corresponding to 0.5 Vp-p microphone output; maximum rate of inhalation (probably limited by the maximum flow rate through the demand valve, and generating about 154 dB SPL) corresponds to 4 Vp-p.

Problems can however occur in the provision of a hermetic seal against moisture ingress for any noise sensor required to work under ambient pressures varying from 1 to 5 bars. The first attempt to achieve this was based on the supposition that about 50% of the volume inside the microphone capsule would be occupied by solid components such as the magnet, leaving 50% as airspace. The microphone measures about 8 × 6 × 4 mm; sound is admitted via a port of diameter about 0.25 mm, located in the centre of one 8 × 6 mm face. A small bubble of thin polyethylene was sealed around the microphone, enclosing about six times the microphone's estimated free internal volume. A ready source of suitable 'bubbles' is an air-cushioned polyethylene packing material commercially available in sheet form.

The microphone is contained in a metal housing, which in turn is sealed into the box containing the related electronics. To check whether the bubble was of sufficient volume to avoid complete collapse at 5 bars, with consequent blocking of the microphone port, a special housing was machined from acrylic material to permit observation. As an additional check on whether the ingress port was blocked, the electrical impedance of the microphone was measured at 1 kHz. This reflects the mechano-acoustic impedance seen by the microphone; at 1 kHz

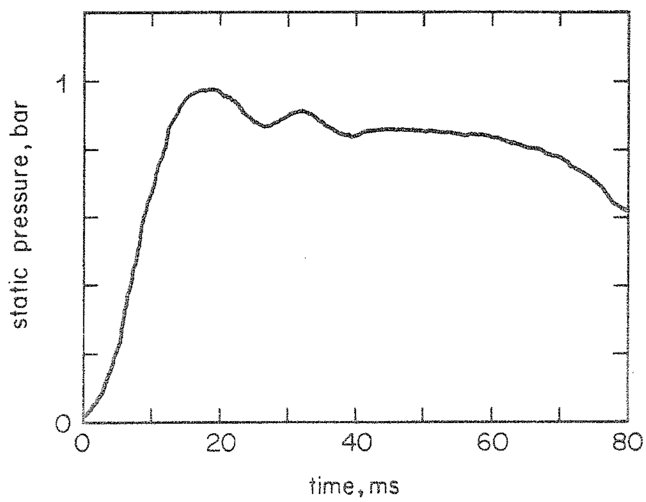

Fig. 3 - Plot of static pressure vs time at demand valve output for very sharply intaken breath.

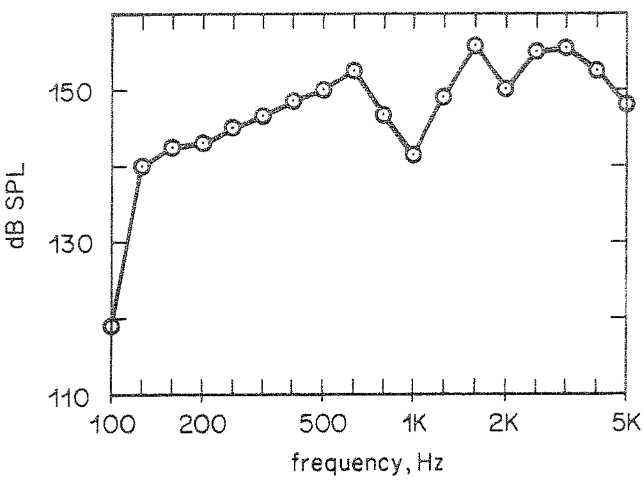

Fig. 4 - Peak noise spectrum in one-third octaves at demand valve outlet for very sharply intaken breath.

under normal conditions it is largely inductive, reflecting the mechanical compliance of the diaphragm.

When the port is blocked, the inductance changes from about 600 mH to 100 mH at atmospheric pressure. Fig. 5 shows plots of inductance against pressure (a) for the microphone on its own, and (b) with a bubble seal. The sharp discontinuity in curve (b) shows that the port is obscured at quite a low external pressure; this occurs because the bubble assumes an irregular wrinkled shape, an event which was unforeseen and which proved the value of the transparent housing. The solution adopted was the partial replacement of the air in the bubble by a substance of lower limiting compressibility; in this case felt was chosen. The inductance curve (c) is for a microphone in a bubble containing a small cylindrical pellet of felt; it follows much more closely that of the microphone on its own, curve (a), showing that it is possible to obtain a hermetic seal without greatly affecting the microphone's acoustic properties. In practice, the felt needs to be separated from the front face of the microphone by a layer of woven-wire gauze to prevent it blocking the port; the details of Fig. 6 show the physical construction finally adopted. This arrangement was shown to work satisfactorily at pressures of up to 7 bars, the maximum that could be conveniently obtained with the available facilities.

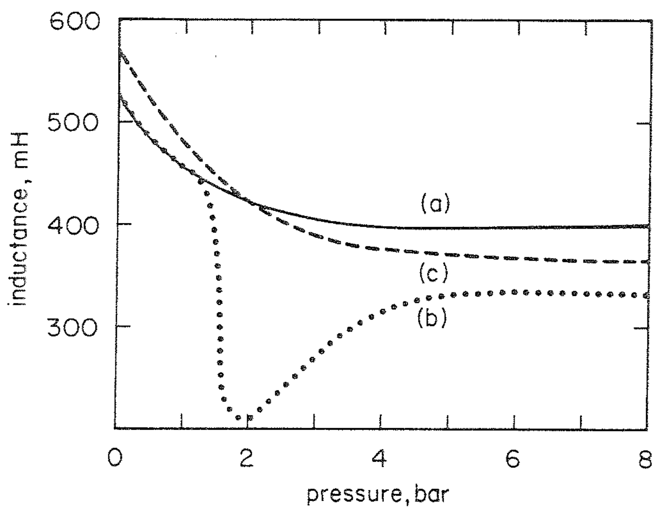

Fig. 5 - Plot of microphone inductance vs pressure for various sealing arrangements.

(a) Without seal
(b) With bubble seal only
(c) With bubble seal partly filled by pellet of felt

4. NOISE-GATE CIRCUITRY

4.1 User requirements

In previous diving work, the signal from the speech microphone had been relayed to the surface by cable without amplification, and some crosstalk had

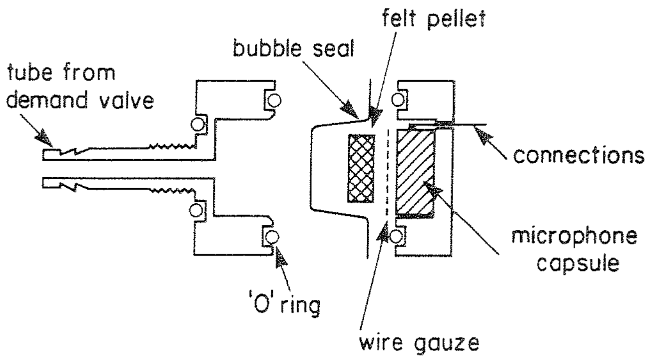

Fig. 6 - Assembly diagram of housing for noise microphone capsule, showing details of hermetic seal.

occurred between the microphone conductors and those carrying the relatively high-level signal to the diver's earpiece. It was considered by the users that a 30 dB gain stage would provide a convenient signal level from their chosen speech microphone (a Shure SM10A, and essentially eliminate crosstalk and cable noise problems, even if the present 200 m cable length were to be doubled as currently proposed.

Another requirement of the circuit design was that it should be powered by its own battery, both to minimise the number of cable cores and to avoid the noise problems mentioned above which can occur with underwater connectors carrying both DC and audio signals. A PP3 (9V) battery was chosen because of its small size, universal availability, and convenient voltage. Its typical life is about 100 hours to 'exhaustion' at 7 V, so there is no need for an on/off switch with its attendant waterproofing problems. In practice, a new battery is fitted at the start of each day's diving, so that the probability of failure during a broadcast is extremely small.

Experience gained in using the previous noise suppressor had shown that it was undesirable to suppress the demand-valve noise completely, because this led to unnatural silences; indeed, the objective has always been to preserve verisimilitude as far as is compatible with comfortable listening. The optimum degree of suppression seems to be around 20 dB, which is the value chosen for the new equipment.

4.2 Circuit operation

The circuit diagram of the equipment is shown in Fig. 7. It is based on a quad CMOS operational amplifier chip, which is compact, economical on power, and has an output voltage swing capability of close to 100% of supply voltage. The noise signal is amplified, peak-rectified, and compared to a reference voltage. At a predetermined noise level corresponding to 'light' inhalation, the FET TR2 is switched off, reducing the gain of the output stage by 20 dB. Some hysteresis is provided so that the circuit does not

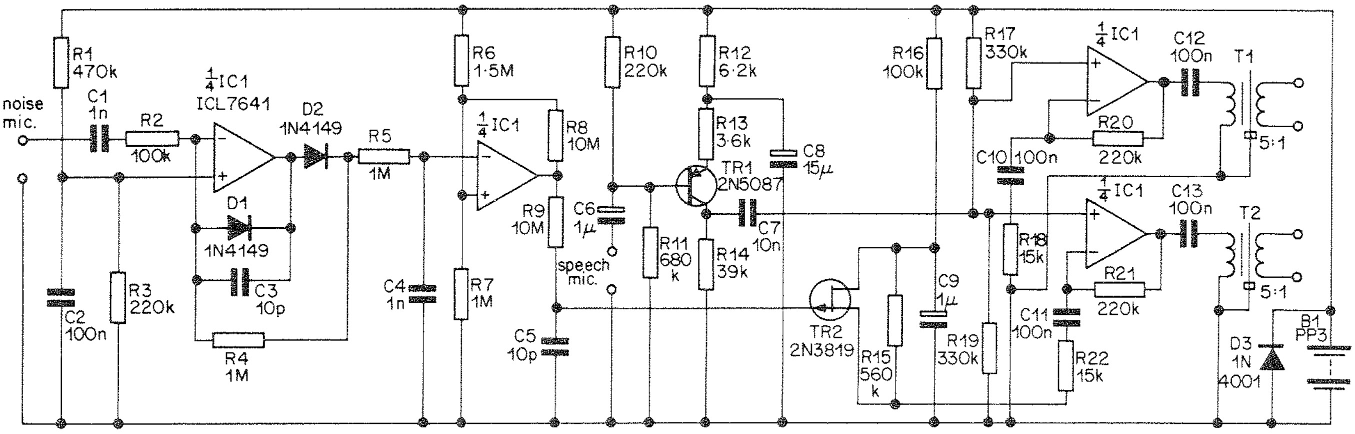

Fig. 7 - Circuit diagram of noise suppressor.

Transformers: Beyer TR/BV 352 005 003

'dither' on the point of switching. No absolute voltage reference is provided, so that the switching threshold is proportional to battery voltage; but a drop from 9 V to 7 V changes the noise level at which switching occurs by only 2 dB, which for the required purpose of the equipment is negligible. At the request of the users, an unswitched output stage was provided as a backup channel. The output stages are driven from a speech microphone preamplifier TR1 which provides a low-noise front end (CMOS amplifiers have poor noise performance at low input impedances). The output transformers have a stepdown ratio of 5:1, which makes it easy to drive low-impedance loads from low-current output stages; the equipment will readily drive 400 m of commonly available cable, which appears as a capacitive load of about 30 nF.

When the equipment is used with a microphone of sensitivity 500 μV/Pa, it provides an overload margin of about 23 dB relative to 'normal' speech.

5. CONCLUSION

A very simple piece of equipment has been designed which can be accommodated within a typical diving helmet, and which combines a microphone preamplifier with a noise gate to attenuate air demand-valve noise to an acceptable level. The device has potential applications both in broadcasting and in commercial diving.

6. REFERENCE

1. D.J. MEARES and K.F.L. LANSDOWNE, 1981. Improvements to speech quality from a diving helmet. BBC Research Department Report No. BBC RD 1981/9.